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Research Article

A Digital Twin for the Logistics System of a Manufacturing Enterprise Using Industrial IoT

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ABSTRACT:

This article presents a Digital Twin (DT) for the logistics system of a manufacturing enterprise using industrial IoT. DT data technology allows to find the required knowledge that can be interpreted and used to support the process of decision-making in the management of the enterprise. The authors propose a classification of DTs for manufacturing and a systematic approach to DT application, as well as its use for simulation of real logistics systems.

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Introduction

Today, logistics plays a key role in the enterprise. Logistics processes also include material and information flow. Planning is the most important factor that determines the efficiency and functionality of logistics in general. In the internal structure of the enterprise, all stages of transportation of products must be uninterrupted and take a minimum amount of time. The main stages of the enterprise are divided into: product manufacturing, storage and preparation for shipment, transportation to the final recipient. At the same time, the location of manufacturing facilities plays an important role in the enterprise, which should be optimized in such a way as to ensure the

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technological process at the right stages. However, planning their placement does not always give the desired result and therefore the creation of a virtual model of manufacturing is a necessity in today's world for the optimal location of manufacturing facilities.[1]

There exist a lot of industrial high-tech solutions in different branches of manufacturing, especially for creation of the virtual model of manufacturing. One of them is Digital Twin.[2] The organization's DTs appear to create organizational processes models that allow real-time monitoring and process efficiency. Besides, the manufacturing side has partial coverage with Industrial IoT (IIoT).

The purpose of the study is to focus on conception, structure and application of DT for logistics system of the manufacturing enterprise using Industrial IoT (IIoT) and creating a program to facilitate the planning of the logistics system of the enterprise by creating a digital twin of the enterprise, which will allow one to see how manufacturing will work in a particular scheme of planning the logistics system of manufacturing, without much modeling costs. Achieving this goal determines the solution of the following tasks: optimize the planning of the logistics system; to create a virtual duplicate of the logistics system of the manufacturing enterprise; calculate the time spent per unit of product.

The results of the development are aimed at optimizing the planning of the logistics system at the manufacturing plant that has the same machines. The program is designed for a narrow area of logistics system planning, but has prospects for development and development in other areas of logistics.

State of the Art

Toward Digital Twin application in manufacturing using of Artificial Intelligence (AI) and Industrial IoT was considered in paper.[3] The paper focuses on DT in Manufacturing using AI and IIoT. An important advantage of this technology, including simulation capabilities, has very attractive prospects in the industry, as it allows prediction of breakdowns, optimization of service plans and conducting the quality improvements more accurately.

The national movement Industry 4.0 is based on additional technologies such as IIoT platforms and others. The Ukrainian company IT-Enterprise[4] is the leader of movement Industry 4.0 in the category of IT companies and the leader in promotion 4.0. The company conducts many events, releases case studies, success stories and more. The Industry 4.0 movement includes application of IIoT.

In March 2018 the first Ukrainian Case Industry 4.0 is published implementation of the SmartFactory IT-Enterprise solution at PJSC "FED,"[5] which is a manufacturing enterprise in Ukraine.

This APS (Advanced Planning & Scheduling) solution is classic enough for World 3.0, contains at the same time elements for World 4.0 such as deep integration with enterprise resource planning (ERP) and manufacturing execution (MES) systems, application of mobile applications, augmented reality and more. The process approach to the organization of manufacturing has

implemented in the company "FED." So, the company is actively implementing virtualization technology – DT. It is a virtual copy of the real physical object, including its dynamics behaviour in the environment. This technology, including simulation capabilities, has very attractive prospects in the industry, as it allows one to predict breakdowns, optimize service plans, and improve quality more accurately. This technology perfectly integrates with IoT,[6] AI,[7] and Virtual and Augmented Reality.[8]

The concept of DT [9] is part of the Industry 4.0 movement [10] and is designed to help enterprises more quickly detect physical problems,[11] more accurately predict their results [12] and produce better products.[13]

An important role is played by Internet technologies as the IoT [14] that provide communications between manufacturing and DT.[15] It is open the direct road to the creation of fully automated industries.[16] IoT is used to improve the decision-making process at the enterprise by providing information about maintenance and reliability as well as data on new products and increased efficiency of manufacturing.

Having DT,[17] it can be reduced the magnitude number of field tests, attempts of technical processes development – all that is connected with the manufacture of the real material part and its tests, the cost of which is much higher than the cost of mathematical modelling.[18]

Digital Twin and IIoT for Manufacture and Logistics

DT as an approach to support management effectiveness is popular in any field of industry, in particular, for manufacturing processes, as it significantly increases the optimization of manufacturing, helps in training by training to work with equipment in a virtual manufacturing model.[19] We suggest the following classification of Digital Twins (see Fig. 1). There are four main classification attributes: distribution, object, purpose and systems. Each of them has a few kinds of DT. Also, DT is a sophisticated software product that is created based on a wide variety of data and technologies, and combines software with special data to create live digital models. DT is constantly updated with changes in physical prototypes.[20] The objects of technology are as individual parts and units of equipment that are part of the logistics system of the enterprise. DT of the existing manufacturing allows to process introduction or change of technological process without real intervention in work.[21]

When using DT significantly increases the speed of technical decisions, while reducing the cost of obtaining the necessary characteristics of the product. With DT it can be reduce the number of experiments in real manufacturing.[22]

Systematic DT based approach to manufacturing management

In the paper we consider some DT coverage. Coverage in mathematics is a family of sets, such that their union contains a given set. Usually, coverings are considered in the general topology, where open coverings (families of open sets) are of most interest. DT almost always has a narrow field of specialization. Therefore, a set of DTs is developed exclusively for a separate manufacturing or

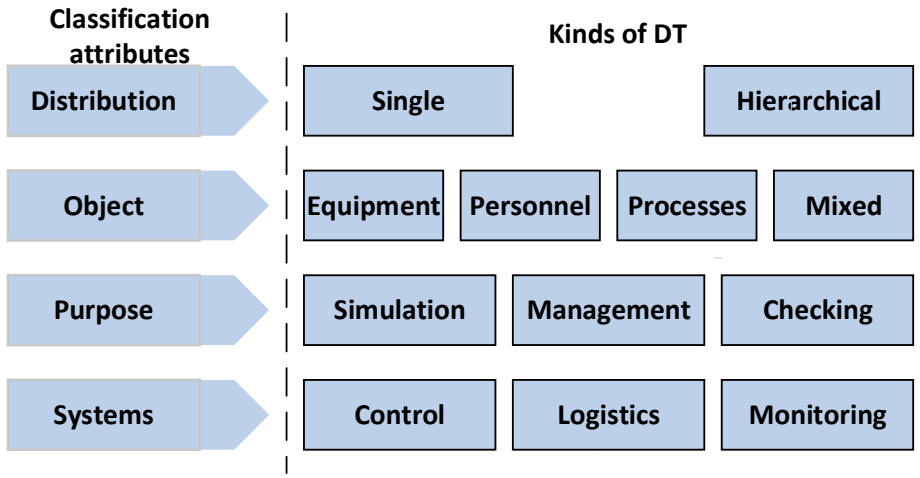

Figure 1: DT Classification.

a narrow specialization, which is the planning of the logistics system of manufacturing (Figures 2 and 3).

The main task of this work is to create DT in the form of software, in which it is possible to plan the logistics system of manufacturing, and calculate the time spent on the manufacture of a unit of product.

The software is executed in a graphical interface on which various objects of manufacturing capacity (machines) will be located and to plan ways between them on which the product will follow till the end of manufacturing.

To implement this software will be developed:

- work surface for planning;
- the button of creation of the machine tool;
- the button of creation of ways between machines;
- pop-up context menu when clicking on the machine to edit machine parameters;
- button to start manufacturing simulation.

As far as there are no strict recommendations for the DT as a software product, it can come in different formats and specializations. The programming language can be selected exclusively for the task.

The collected data is sent to AI, which allows staff to make informed decisions quickly. DT is used for simulation of real enterprise manufacturing for the training of personnel and modelling actions that help optimize business performance.

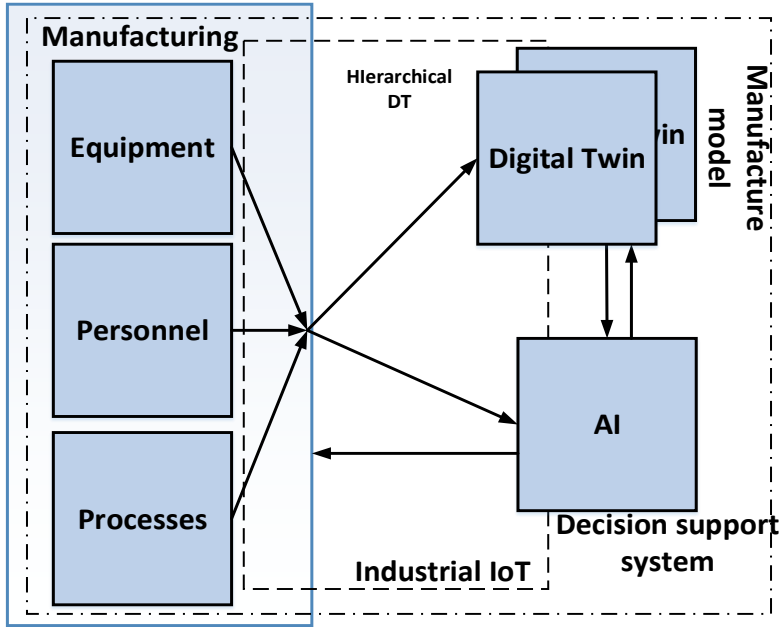

Figure 2: Communications between manufacturing and DT.

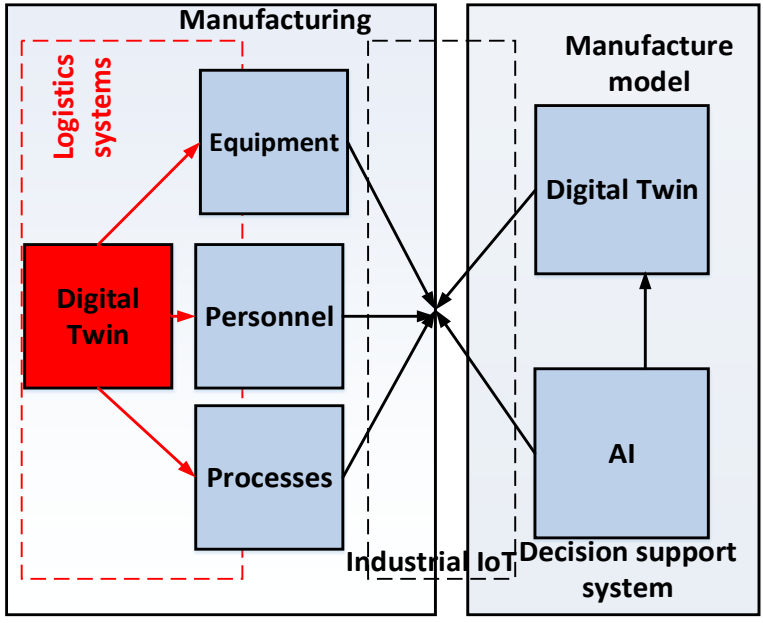

Figure 3: DT for logistics system.

Digital Twin based logistics system. Case study

The considered technology of DT is actively used for simulation of real enterprise manufacturing for logistics system. The DT of the logistics system of a manufacturing enterprise is developing with the use of C# and .NET Framework 4.7.2 programming technology.

Nomenclature equipment of the manufacturing enterprise such as circular grinding machines, turning machines, gear hobbing machines and high-speed vertical milling machining center was represented as pictograms.[23]

It was designed for the aim to calculate the optimal location of manufacturing facilities for maximum productivity. The application allows the user following functions:

1. Creation of new manufacturing facilities

The form for creating new manufacturing facilities appears after clicking on the "Workbench" button in the upper right part of the main form. After pressing this button, the user needs to select the model of the machine that he needs and click on the button with the name of the machine.

The simulation of the machine is performed automatically in the upper left corner, taking into account all the dimensional characteristics of the object (Fig. 4).

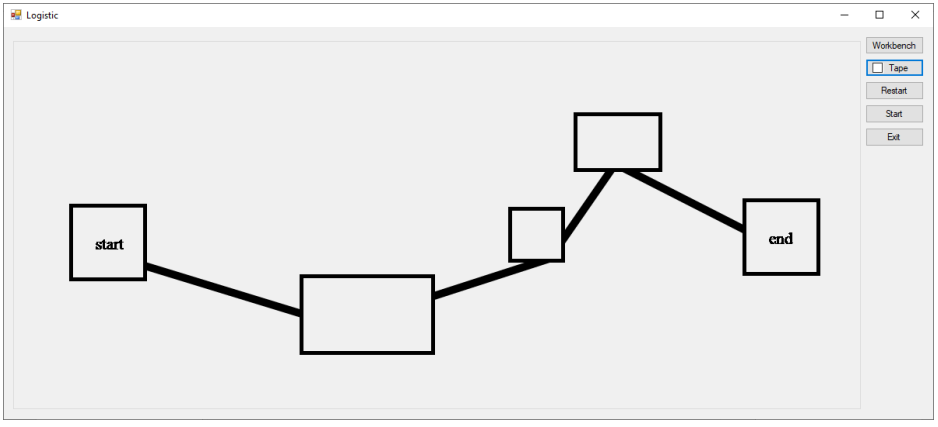

Figure 4: Creating the large number of manufacturing facilities in the application.

2. Deleting a single object

To delete a single object, right-click on the object, then a context menu pops up in which you need to select the "Delete" section. The program will then delete the selected object.

3. Changing the characteristics of the object (machine)

The characteristics of the object change for each individual, regardless of the make and model of the object. To change the characteristics of the object, you

need to right-click on the selected object and select the "Parameters" function in the context menu.

After clicking on a section in the context menu, a separate form with the characteristics of the selected object will appear in which the image of the object and its properties will be displayed, in the description of the object there will be fields to change the characteristics of the object.

4. Construction of routes for transportation of products

To create ways to move products through manufacturing, the main form has a "Tape" key with a radio flag that displays the mode in which the program is, if the application is ready to build a path, the flag is a bird, and vice versa. After the application enters the path build mode, you need to click on the first object you want to connect, then on the second. The application will automatically create a path after these manipulations.

5. Performing calculations

After modeling the logistics system, you need to click "Start", which will start the calculation.

If the logistics system is not built correctly, the application will display an error due to which calculations are impossible, such as the lack of a path from the beginning of manufacturing to its end.

6. Implementation of redevelopment and optimization of the logistics system

If the user is dissatisfied with the result after the calculations, or has ideas to optimize the system, he must click "Restart", which will reload the program resources and erase all paths, but leave the location of machines on the desktop, allowing the user to reschedule their logistics system.

7. Logging out of the application

To exit the application and securely close, there is a special "Exit" key, after pressing the key there will be a safe release of memory resources, and the application will end.

The following steps in the extended functionality of the application:

- expanding the scope;
- creation of additional functionality for manipulation of objects; adding more variety to manufacturing facilities;
- adding the possibility of planning several logistics systems, and the possibility of cooperation between them;
- changing and improving the graphical interface;
- creating the possibility of preserving the created logistics systems.

The suggested software as a fragment DT for logistics system is based on manufacturing processes of JSC “FED”, Kharkiv, Ukraine where its implementation has been planned. Besides, this project is a part of implementing DT based approach for manufacture management including application of integrated security and safety management systems for IT, OT [24] and ET [25] levels.

Conclusions

The development of DT for the logistics system of the enterprise is very important. Important in creating the DT logistics system is the ability to quickly upgrade and optimize manufacturing with the least planning costs.

A special feature of the DT in manufacturing using industrial IoT has been studied in the paper. The purpose of this work was to develop an application that allows to create DT of the logistics system of manufacturing. The subject area of this development is widespread, and is one of the most relevant areas in the creation of commercial applications. Considering the general model of DT, it became clear that it has a number of problems that will be addressed in further research. These problems include the complexity of integration into the existing and developing structures and implementation of DT software support.

It is planned to present algorithmically and mathematically the logistics system, which is based on models in future publications.

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